

# COMPUTATIONAL TECHNIQUES FOR BEAM WAVEGUIDE SYSTEMS

W. A. Imbriale and D. J. Hoppe

*Jet Propulsion Laboratory  
4800 Oak Grove Drive  
Pasadena, CA 91109 USA  
Email: [William.A.Imbriale@jpl.nasa.gov](mailto:William.A.Imbriale@jpl.nasa.gov)*

## INTRODUCTION

Many of the modern Radio Telescopes, especially those at millimeter and submillimeter wavelengths, employ beam waveguide (BWG) systems as part of the relay optics. These systems are typically analyzed by using physical optics, Gaussian beams or ray tracing techniques. Physical optics offers high accuracy at the expense of computation time. At the other end of the spectrum is ray tracing approaches that ignore diffraction effects entirely. These methods are fast but sacrifice the ability to predict some effects accurately.

An intermediate approach is to use an appropriate set of expansion functions to model the field between the reflectors. If the set is chosen wisely only a few coefficients need to be determined from each reflector current. The field is then computed at the next reflector through the use of the expansion functions and their coefficients rather than by using the previous reflector current. For a beam waveguide system with no enclosing tubes an excellent set of expansion functions is the Gaussian beam mode set. In many cases a preliminary design which includes the effects on diffraction may be obtained by considering only the fundamental mode and a thin lens model for the reflectors. Higher-order modes are included to model the effects of the curved reflector, which include asymmetric distortion of the beam, cross polarization, and beam truncation.

This paper describes a methodology for implementing each approach to efficiently calculate the performance of multiple mirror reflector systems. Examples will compare the results of each approach and suggest appropriate conditions under which each should be used.

## GAUSSIAN BEAM ALGORITHM

A computer program has been written to solve the problem of higher-order Gaussian beam scattering by an arbitrary set of reflectors. The problem geometry is depicted in Fig. 1. The steps involved in the solution are as follows:

- (1) Compute the current on the first reflector using physical optics. The incident magnetic field is provided either by a feed model or by an incident set of Gaussian beam modes.
- (2) Compute the direction of propagation for the reflected Gaussian beam-set using ray tracing. Using a gut ray in the input direction specified by the feed coordinate system or by the input Gaussian beam set propagation direction and the reflector surface description compute the gut ray direction for the output Gaussian beam set.
- (3) Next the waist size and location for the output beam set is found by examining the amplitude and phase distribution of the current on the reflector, as described below. Essentially, the waist and radius of curvature of the output beam set at the reflector are estimated. From these two quantities the beam waist and its location along the output gut ray direction are determined.
- (4) Having determined the size of the waist and its location all that remains is to find the amplitudes of the individual modes in the output mode set. This is accomplished through the use of the reciprocity theorem. A calculation of an interaction integral of the mode in question and the reflector current is required.
- (5) Steps (1)–(4) are then repeated for each additional reflector in the chain. In each of these cases the previous Gaussian beam set provides the input field for the current calculation.
- (6) The far field pattern radiated by the final mirror can be computed using physical optics.

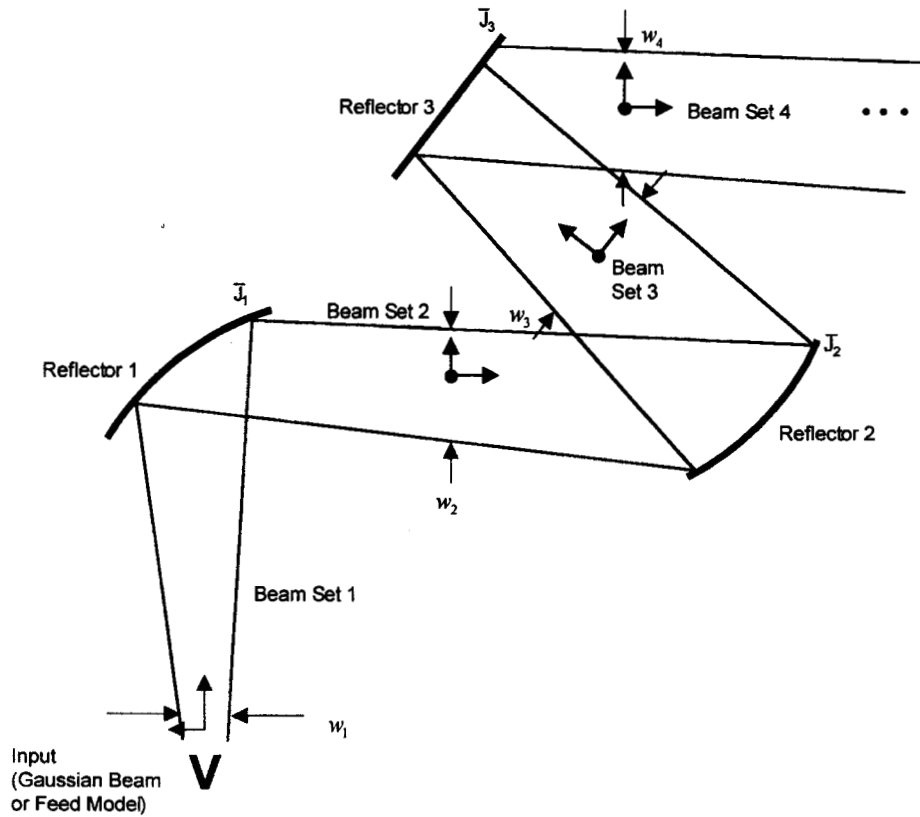


Fig. 1. Problem Geometry

## RAY ANALYSIS ALGORITHM

A bundle of rays is launched from the feed point to the first reflector. The ray distribution in angular space is proportional to the power pattern of the input feed. The rays are then traced through the multiple reflector system. A flat plate is placed a large distance from the final mirror, perpendicular to the central ray. The rays from the final mirror are traced to the flat plate. The density distribution of the rays on the flat plate can be processed to yield the far field pattern scattered from the last mirror.

## PHYSICAL OPTICS ALGORITHM

The physical optics algorithm uses the classical physical optics technique. The currents on the first mirror are computed from the incident field of the feed. The currents on the subsequent mirrors are derived from the fields radiated from the currents on the previous mirror. The currents from the last mirror radiate to produce the output far field pattern. It is assumed that only the subsequent mirror can see currents from the immediately preceding mirror, i.e. currents from earlier mirrors are blocked from it.

## AN EXAMPLE

As an example, consider the 3-curved mirror BWG system used in the NASA/JPL 34-meter R & D BWG antenna. The BWG consists of a beam magnifier ellipse followed by a imaging pair of parabolas. The system is designed to operate from 2 to 35 GHz. Figures 2 and 3 compare the three methods at 2.3 and 32 GHz. Of course, the ray optics technique is frequency independent. Figures 4 compares the first order Gaussian and Physical Optics techniques at 32 GHz. Figure 5 compares first order Gaussian versus higher order Gaussian at 2.3 GHz.

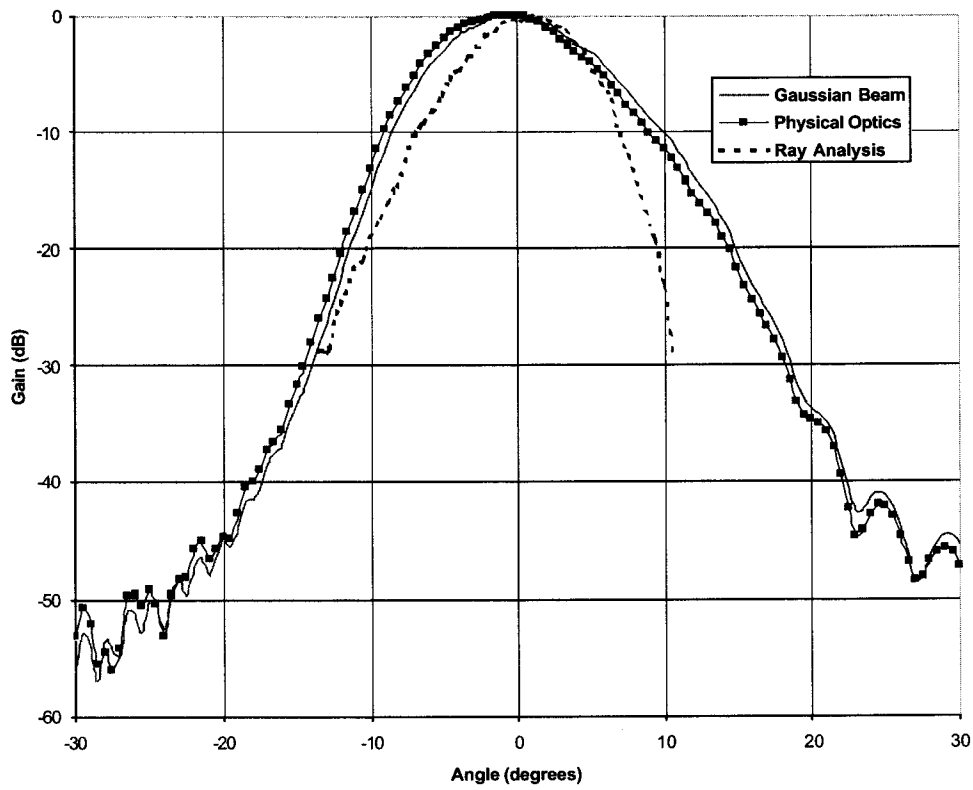


Figure 2 Comparison of three methods at 2.3 GHz

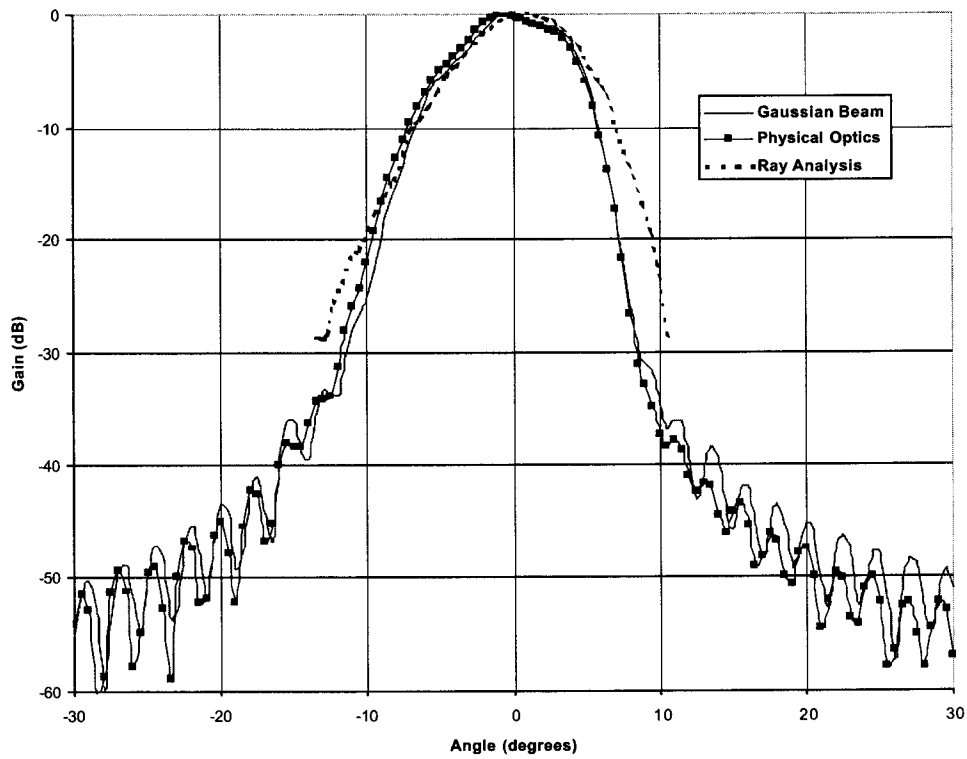


Figure 3 Comparison of three methods at 32 GHz

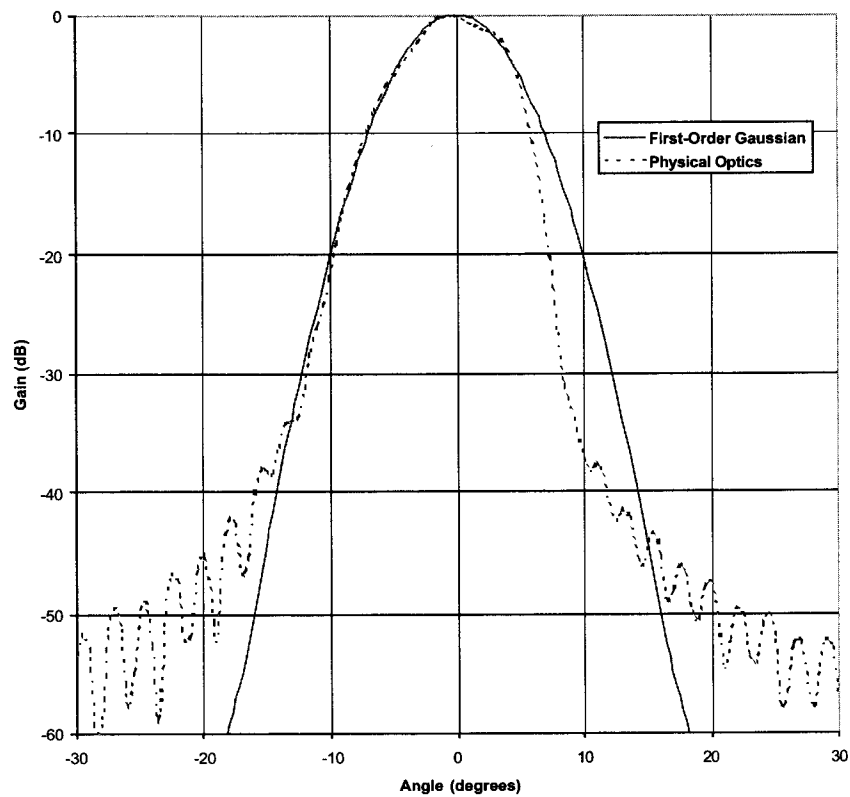


Figure 4 Comparison of first order Gaussian and Physical Optics at 32 GHz

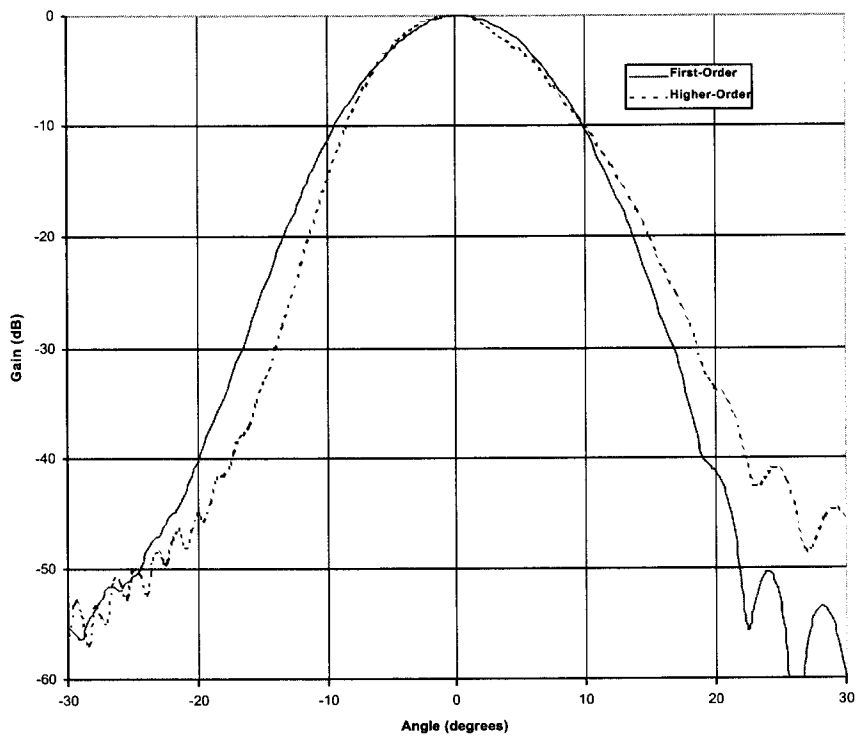


Figure 5 Comparison of first and higher order Gaussian at 2.3 GHz